Technical Subcommittee B

of the

Water Planning Council

Issue 7 - Recommended methods for measurement and estimations of natural flows in Connecticut waterways in order to determine standards for streamflows that will protect the ecology of the state's rivers and streams

Final Report

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Issue 7: Recommended methods for measurement and estimations of natural flows in Connecticut waterways in order to determine standards for streamflows that will protect the ecology of the state's rivers and streams

September 5, 2002 version

Subcommittee B of the Technical Management Committee is charged with addressing Issues 7 and 8 of the Water Planning Council Issues Work Plan. In the early stages of the process the Subcommittee agreed to the following Consensus Approach to addressing Issue 7.

The Subcommittee recognizes that a long-term approach assessment method should take into account unique basin characteristics, but that it will take several years to develop and implement. Consequently, the Subcommittee recommends the use of a simplified method in the interim. Within this context we will address the following areas:

1. Explore interim instream flow methods that are applicable to Connecticut's rivers and could be applied over the next 5 years as a more detailed and sophisticated long-term method(s) is established. Make a concerted effort to identify the most appropriate interim method for Connecticut.

2. Establish a scientific framework to create and implement long-term instream flow protocol(s) and standards for Connecticut's rivers to use in water allocation processes. The subcommittee will identify those variables and site-specific criteria to serve as the foundation of the long-term protocol(s). The framework is proposed to be initiated within one year of the completion of the WPC final report and completed within five years therefrom.

3. Identify a process for review and revision of Connecticut instream flow method(s) to ensure the state is using the best and most current method(s) to establish instream flow standards.

4. Identify the cost for such work and the strategies to obtain the required funding.

5. Identify how such information will be implemented and used by state agencies and others for regulatory and non-regulatory purposes.

I. Introduction

The goals to be achieved must be established before evaluating and proposing appropriate methods for measuring and estimating flows. The task that Issue 7 describes is to identify "methods for measurement and estimations of natural flows in Connecticut waterways in order to determine standards for stream flows that will protect the ecology of the state's rivers and streams." Similarly one of the "Possible Areas to Investigate" is "what stream flow standards are needed to protect the chemical, physical, and biological integrity of the state's rivers and streams". Thus, the goal of the proposed method is to provide estimates of monthly streamflow statistics that are presumed to be protective of the streamflow ecology in an unregulated watershed.

Researchers have identified five critical components of the flow regime that regulate ecological processes in river ecosystems: the magnitude frequency, duration, timing and rate of change of hydrologic conditions. These components influence ecological integrity both directly and indirectly, through their effects on other primary regulators of integrity. Modification of flow thus has cascading effects on the ecological integrity of rivers. (Poff et al., 1997)

Ecologically protective flows are considered to be flows that support desirable biota at densities similar to those expected under natural (i.e., unregulated) conditions. It is acknowledged that natural flows may not be optimal flows and that natural variability in flow over time may adversely impact aquatic biota even in the absence of human influence. According to Armstrong et al., 2001 streams have a natural flow regime that varies within an annual cycle, between wet, dry and normal years, and from upstream to downstream. Consequently , streamflows cannot be expected to meet a minimum summertime requirement at all times or at all sites. Favorable flows for one life stage of a species are often different than those for another stage of the same species, and flow needs of different species can vary tremendously. A wide range of flow magnitudes occur naturally and human needs and actions (e.g., development, dams, withdrawals, discharges) often alter critical components of the flow regime, ie. duration or frequency of flows. Alterations of the natural flow regime may not always be to the detriment of the biota. In the absence of site-specific data that allow a better understanding of relations between flow and biotic integrity, flows are sought that generally mimic the essential components of the natural flow regime under the assumption that ecological processes will then foster a desirable aquatic community.

Section 22a-426 of the Connecticut General Statutes (CGS) mandates standards of water quality to preserve and enhance the quality of State waters for present and future use for public water supplies, propagation of fish and aquatic life and wildlife, recreational purposes and agriculture, industrial, and other legitimate uses. The federal Clean Water Act (CWA, Section 303(c)) and its implementing regulations require states to adopt designated uses, water quality criteria to protect those uses, and an antidegradation policy, for all surface waters. EPA's regulations require that state water quality standards should: provide, wherever attainable, water quality for the protection and propagation of fish, shellfish and wildlife, and recreation in and on the water ("fishable/swimmable ") and consider the use and value of State waters for public water supplies, propagation of fish and wildlife, recreation, agriculture and industrial purposed and navigation. EPA's regulations require the State to include these "fishable/swimmable " uses as designated uses for all surface waters unless the State demonstrates that such uses cannot be attained for certain reasons. Connecticut Water Quality Standards set forth a fundamental goal of restoring and maintaining the chemical, physical, and biological integrity of Connecticut surface waters, and establish designated uses for all inland surface waters including recreational use, fish and wildlife habitat, agricultural and industrial supply and other purposes. Some surface waters have specific designated uses for existing water supply or potential future water supply. The criteria associated with the attainment of these "designated uses" allow for aquatic communities to exhibit characteristics brought about by natural hydrologic and geologic conditions.

Altered stream flows may adversely affect stream ecology. For example there may be increased water temperatures, decreased dissolved oxygen levels and increased fine sediment deposition, which can result in a shift from cold water to warm water fish species, leading to decreased productivity and increased fish kills, and making stream bottoms unsuitable for fish spawning. Low flows can also affect the ability of rivers and streams to assimilate wastewater. These effects and others are discussed more thoroughly in the Water Allocation Task Force Report, Ecological Needs Section (MacBroom & Jacobson, 1999) (Appendix A) and other sources (Poff et al., 1997).

The recommendations of this subcommittee include methods for the estimation of natural flows to aid in determining future standards that will protect the ecology of the state's rivers and streams. Flows calculated by these methods should be used to set a context for future streamflow standard regulations and allocation decision making. These natural flow estimates should not be directly applied as a streamflow standard. Natural flow estimates may provide the basis for developing future instream ecological goals following additional evaluation of their ecological benefit and their potential impacts on water uses, particularly public water supply. These evaluations should include analysis of the following potential impacts: loss of public water supply safe yield; increased frequency of public water supply drought restrictions; and economic and social effects. The actual impact on public water supply and other water uses will depend upon the way in which the flow goals are implemented and integrated with adaptive management strategies and conservation practices to protect the river resource and use it as efficiently as possible. (see Section VI). Prior to utilizing any method to aid in determining future stream flow standards, the relationship between flow and habitat value must be scientifically established for all months of the year.

While the ultimate allocation of the state's water resources is beyond the purview of this Subcommittee, it is important that the proposed methods be understood and applied in a balanced context that accounts for the needs of, and impacts to, all lawful water users. The recommended methods should provide policy makers and regulators with the tools necessary to work toward the goal of maintaining or restoring instream habitat without compromising the adequacy of water supplies now or in the future. Before they are applied, the recommended stream flow methods must be rigorously tested to determine their effects on industry, public utilities, water supply, public safety, agriculture, aquatic habitat and other lawful uses of water. Achieving instream ecological goals may not be feasible in some streams due to water use priorities, economic limitations, or physical or technological constraints. Other alternatives such as system interconnection should be explored if these goals are not being met.

II. Background

The Subcommittee reviewed a variety of instream flow methods. It was decided that both an interim and long-term method will be necessary to meet the Issue 7 objective. Reconnaissance-level techniques were determined to be appropriate interim methods. Incremental techniques were determined to be appropriate long-term methods. The Subcommittee heard several presentations on these techniques, and copies on the presentations are included in the appendices to this report.

Reconnaissance-level typically involves desktop, rule-of-thumb methods for identifying instream ecological goals. Most of these require data on the hydrologic records of the stream. The use of these records assumes that measured flows support aquatic resources at acceptable levels (Stalnaker, 1994). Techniques reviewed include ABF, Tennant Method, Range of Variability Approach, and the Connecticut Aquatic Base Flow Method. The Subcommittee also reviewed additional techniques including the Wetted Perimeter and R-2 Cross methods, which are reconnaissance techniques that require collection of empirical data(see Appendix B). Ways to estimate natural flows at ungaged locations include rainfall runoff modeling and the QPPQ Transform method. (see Appendix E)

Incremental techniques were also evaluated by the Subcommittee. Incremental techniques are site –specific analyses that examine multiple decision variables and enable different flow management alternatives to be explored (IFC, 2000). The best known and most widely used incremental method is the Instream Flow Incremental Methodology (IFIM). An IFIM analysis typically involves a collection of computer models, with Physical Habitat Simulation System (PHABSIM) commonly serving as the foundation for modeling habitat response to changes in instream flow. Less costly qualitative and empirical techniques may be used in some cases. Another model, the Meso-Habitat Simulation System (MesoHABSIM), which can serve as the foundation for an IFIM analysis is being used in New England (Parasiewicz, 2001). This approach maps at a mesohabitat level by setting the precision of hydraulic sampling to larger units and increasing the emphasis of system scale mapping.

Due to the highly technical nature of the issues assigned to Technical Management Subcommittee B and the varied backgrounds of the Subcommittee members, a substantial amount of meeting time was devoted to educational presentations in the following areas:

1. Reconnaissance-level methods for identifying instream ecological goals

2. The components of establishing long-term stream flow methods (incremental methods),
3. The components of an optimal stream gage network and statistical methods for the estimation of flow on ungaged streams,
4. Probability, flow statistics and time scale, and using these techniques to assess the sensitivity of reservoir firm yield to instream flow releases.

As a result of the time devoted to education and the rather short time-frame provided for completing reports on these issues, the time remaining was inadequate for a comprehensive exploration and debate of the issues. Thus, some issues remain unresolved and require further investigation.

III. Recommendation - Interim Method

Appendix B summarizes each of the interim techniques evaluated. More detailed discussions and evaluations of the techniques can be found in *Instream Flows for Riverine Resource Stewardship* (IFC, 2002) and in a Yale School of Forestry Masters Thesis, "Instream Flow Protection in New England: Status, Critique, and New Approaches to Standard-Setting." (Apse, 2000).

The majority of the Subcommittee recommends consideration of a reconnaissance-level technique as a reasonable interim method which identifies flows that are presumed to be protective of instream ecology until more detailed and sophisticated methods are developed. Reconnaissance-level approaches are relatively inexpensive, fast, and appropriate as planning tools where there are few decision variables. However, they have little predictive function, are based on relatively generic information and do not support negotiated solutions.

While these methods may be represented by natural stream flow statistics, the relationship between the estimated flows and habitat value is not thoroughly understood on a site-specific basis. The Subcommittee recognizes that for the long-term, an ecologically based method or methods will need to be developed that scientifically establishes the site-specific relationship between flow and habitat value during all months.

The Subcommittee recommends that an interim method for estimating ecologically protective instream flows should only be used as a basis for:

- Developing water quantity goals, with a balanced and realistic framework such as the Water Quantity Goals Framework discussed in Section V
- Water resources planning,
- As a basis for applying professional judgment in environmental analyses and permitting,

There is agreement by the majority of the committee that the approach developed by Apse (2000), the median of daily flows for each of the months of October through June for unregulated rivers throughout Connecticut, is a reasonable reconnaissance-level approach to estimating ecologically protective instream flow in those months for steps 1 and 2a below.

The Subcommittee does not have agreement on the flow statistics for steps 1 and 2a below for the months of July, August and September. Some members of the Subcommittee support the Apse (2000) recommendation of a more conservative statistic (more water in the river), see Table 2, column 2; the median of the monthly mean flows (FWS ABF). Other members of the Subcommittee recommend applying the median of daily flow statistics for each of the twelve months (less conservative), see Table 2, column 1. The choice of monthly flow statistics for July, August, and September is an allocation decision.

The Subcommittee recommends the following approach to applying an interim method, with the exception that there is not unanimous agreement that the flow statistics described in Apse (2000) are the most appropriate for addressing items 1 and 2a:

1. If the site is located in one of the ten unregulated gaged basins analyzed in the Apse (2000) study, use the statistics listed in Table 4.
2. If the site is located outside one of the ten Apse (2000) basins
    a. Use monthly statistics from Table 2 (statewide default criteria)
    b. or estimate monthly statistics using natural daily flows generated by rainfall-runoff models or the QPPQ transform (see Appendix E).
    c. or estimate monthly statistics if located within an alternative gaged watershed identified by USGS as being suitably unregulated, and having a sufficiently long-term record.
3. Alternatively, scientifically defensible site-specific studies may be conducted to determine ecologically protective flows.

IV. Long-Term Methods Evaluated

Summary of Techniques

Dr. Clair Stalnaker, USGS emeritus scientist, gave a keynote presentation at last year's Connecticut Instream Flow Conference in Berlin, Connecticut. He described key ecosystem components necessary to protect the processes and functions of a river ecosystem. These include consideration of: hydrology, geomorphology, biology, water quality and connectivity. In the Instream Flow Council's recent publication, *Instream Flows for Riverine Resource Stewardship* (IFC, 2002) the same components were identified as necessary to develop instream flow prescriptions which mimic the natural flow regime as closely as possible.

An ecologically based instream flow regime, according to Stalnaker, should accomplish the following:

1. Maintain seasonal variability (intra-annual)
2. Maintain long term variability (inter-annual)
3. Maintain habitat diversity
4. Maintain biodiversity

5. Assure healthy aquatic communities
6. Result in flow prescriptions for wet, average and dry conditions

In addition to reviewing reconnaissance-level approaches, the Subcommittee also examined incremental techniques and other materials dealing with statewide flow methods. For example the Subcommittee reviewed the approaches taken by other New England states, in particular, the New Hampshire instream flow rules procedures for establishing "protected instream flows."

Incremental techniques are site –specific analyses that examine multiple decision variables and enable different flow management alternatives to be explored. (IFC, 2002) The best known and most widely used incremental method is the Instream Flow Incremental Methodology (IFIM). The IFIM includes several computer models including PHABSIM. Another incremental technique which is being used in New England is the MesoHABSIM approach (Parasiewicz, 2001).

At the May 2002 Subcommittee meeting Dr. Piotr Parasiewicz from the Instream Habitat Program at Cornell University presented more detailed information on the mesohabitat approach and his idea for a statewide assessment program which addresses the five key ecosystem components. Refer to Appendix B for a portion of his presentation.

Proposed Long-Term Approach for Connecticut

The Subcommittee recommends that the following framework for quantifying the relationship between instream flow and habitat suitability be adopted to create and implement a long-term instream flow protocol for Connecticut's rivers and streams. This approach takes into account unique basin characteristics and provides more accurate and refined data for use in water resources planning, regulatory decision-making, and working toward achieving long-term water quantity goals. This may provide the basis for establishing future water quantity standards within the context of a balanced water allocation process.

1. Target Fish Community Regions. The first step would involve the determination of a set of target communities (Bain and Meixler, 2000) occurring in Connecticut and their spatial validity. The state would be delineated into four or five zoogeographical sub-regions. A target fish community (or communities) would be defined for each of these regions, for big and small rivers separately.

The Target Fish Community approach defines a fish community that is appropriate for a natural river in southern New England by specifying common members, the balance of abundances, species organization, and biological attributes. It uses an inference approach to summarize the ways that a current community differs from target conditions. The target community is used as a benchmark for assessing comparability and also to identify the nature of departures. It serves as a target for river enhancements and as an endpoint for evaluating program progress.

The theoretical basis of the target community concept is similar to that cited for the development of Index of Biological Integrity (IBI)-type approaches, i.e., the operational definition of biological integrity first developed by Karr and Dudley (1981), the definition of community (i.e., assemblage) attributes, including their proportions and membership, the assignment of fish species to various guilds (e.g., macrohabitat generalists and fluvial specialists), and the use of least impacted reference condition (similar rivers) to define "natural." The target community approach is consistent with Clean Water Act goals to restore and maintain the physical, chemical and biological integrity of the Nation's Waters.

Target Fish Communities have also been developed by State and Federal interagency teams for the Ipswich in Massachusetts and the Lamprey River in New Hampshire. Plans are underway in 2002 to develop Target Fish Communities for the Charles and Housatonic Rivers as part of the Massachusetts Executive Office Environmental Affairs watershed planning cycle. It is identified in the Massachusetts Water Resources Commissions Stressed Basin Report as a key way to determine habitat impairment.

2. <u>Habitat selection criteria</u>. For every community, define the habitat selection criteria of the dominating species and life stages, using a combination of electrofishing with underwater and on-shore observations. These criteria would be developed for each season in good quality river reaches and would comprise a regionally valid set.

3. <u>Fish Habitat Regions.</u> Next follows the delineation of the state into hydro morphological regions based on available hydrological, geological, land form and land use data. Subsequently, fish community- and hydromorphological regions are overlaid creating fish habitat regions that define specific physical settings and corresponding fish fauna as a product. For each fish habitat region one or two representative watersheds are selected. What follows is a stratified census, or inventory, of low-flow mesohabitats for these watersheds. Small rivers can be mapped in river-hike surveys and larger ones combining aerial videography with on-the-ground survey.

4. <u>Habitat model.</u> Development of a habitat-flow relationship for each watershed. Following the rigorous approach developed on the Quinebaug River, select a number of representative sites to be mapped at various flow conditions and then establish the MesoHABSIM model.

5. <u>Habitographs</u> Based on habitat time-series analysis (including reproduction of "pre-colonial or unregulated" hydrographs) and the "continuous-under-threshold" technique developed in France determine habitat thresholds, (specifically, the lowest allowable and the highest probable level of habitat). This step would produce seasonal habitat time series, habitat duration curves and, finally, continuous under-threshold duration curves. Such target habitographs would be generated for each fish habitat region.

6. <u>Application in individual cases:</u> To determine the deviation from target habitograph for any watershed in the region, habitat time series are converted to hydrological time series and compared with present hydrographs applying the Range of Variability Approach developed by

the Nature Conservancy. This technique describes natural range of inter- and intra-annual hydrograph fluctuations, as determined by the statistical analysis of historical hydrographs. The sole use of historical hydrographs presents problems, however, due to landscape changes and historical impacts ,which predate the installation of a particular gauge. As a result target hydrographs should be used.

Because the target habitograph takes into account the interplay of flow and habitat structure the improvement in impacted streams could be achieved in two ways: either by changing the flow scheme or by optimization of habitat structure. Therefore to maximize the amount of water used for other than ecological purposes the potential for improvement of habitat structure by, for example channel restoration or dam removals can be utilized first. The watershed scale of this approach would also allow for analysis of impact mitigation by replacement measures i.e. trades-off of the habitats in different locations.

7. Impact simulator. To effectively handle all sets of options and perform adequate optimization it is necessary to provide a Windows based computer software, that could be used by resource managers and users. This quantitative simulation package should build upon MesoHABSIM and serve as a comprehensive tool for analyzing the impact of various resource-use scenarios. It will predict the habitat quantity and quality for definable portions of the river ranging from individual reaches up to an entire watershed. Furthermore, it should allow to integrate the habitographs with water quality, temperature, life history, and climatic change issues and develop catalogs of integrative management measures for each watershed in the region.

V. Application Issues

In the previous sections, the Subcommittee focused on recommending methods to estimate instream flows to protect the ecology of the state's rivers and streams and to protect their chemical, physical and biological integrity. The question remains how to apply these methods.

Analysis of Costs and Benefits

Natural flow estimates may provide the basis for developing future instream ecological goals following additional evaluation of their ecological benefit and their potential impacts on other legitimate water uses, particularly public water supply. These evaluations should include analysis of the following potential impacts: loss of public water supply safe yield and margin of safety; increased frequency of public water supply drought restrictions; and economic and social effects.

Concerns have been raised by some members of the Subcommittee about the effects of the proposed recommendations on existing authorized diversions. Before implementation of any instream flow method as a regulatory standard, the effects on existing water diversion operations must be fully evaluated.

Members of the Subcommittee agree that costs and benefits to aquatic resources be included in the evaluation.

The analysis of costs to industry, public utilities, water supply, agriculture, and other users should include the implementation costs such as infrastructure changes to make releases, operational costs for personnel to operate valves to make releases, flow monitoring and other capital, operation and maintenance needs. The analysis should simultaneously consider these costs, costs to aquatic resources and recreational users (anglers, boaters), and the benefits to aquatic resources and humans of more natural flows..

The total costs for implementing instream flow goals must be tallied and then a determination must be made as to who will pay for them. The burden of such cost should not be borne solely by the water utilities and their ratepayers.

In view of the competition for clean water, and the reduced reservoir yields when instream flows are provided, it is imperative for water suppliers to carefully assess water demand and alternative sources of water. Based on a simulation model assessment and presentation by Dr. Neil M. Fennessey (2002) to the Subcommittee and subsequent discussions and analysis, it has become apparent that there may be significant impacts to public water supply from application of instream flow methods. One evaluation estimated that application of the Apse (2000) monthly statistics and limiting outflow to less than or equal to inflow, would result in as much as 90 percent reduction in a reservoir's firm yield (see Appendix D) (NOTE: Appendix D is an analysis of potential impacts to water supply only. Strategies to mitigate these potential impacts, as recommended by the Subcommittee include water conservation, effective demand side management, effective stormwater management, etc.)

Increased instream flow releases from reservoirs, and\or reduced pumping from wells could significantly reduce their Safe Yield and Margin of Safety. Since State regulators require Public Water Suppliers to have a minimum Margin of Safety, increased instream flow releases may put a water utility out of compliance. Prior to implementing any interim or long-term methods the Subcommittee recommends that these methods need to be fully evaluated tested to determine the impact on overall public health and safety and the economic well-being of State of Connecticut. As a counterpoint the benefits to the aquatic resources due to the increased flow rates and the costs to aquatic resources by not releasing additional water should be evaluated simultaneously.

Implementation of instream flow standards must be carefully developed for situations where wells are involved to address time lags and induced recharge from nearby water courses.

These and other water supply impact issues are discussed further in Appendix D (Note: Again, this appendix is not supported by the full committee – see above reference to Appendix D)

<u>Groundwater Diversions</u>

Unlike surface water reservoirs where high flows can be stored for later use, well fields in Connecticut rely on the water naturally stored in the aquifer during precipitation and snowmelt events, and in some cases, induced infiltration from adjacent streams. Although Connecticut's stratified drift aquifers store vast quantities of water, pumping can have an impact on the river flows. The lag time between when pumping occurs and when streamflow impacts are felt depend on several factors, and can range from hours to weeks or even months.

Operators of surface water reservoirs can alter their releases (up or down) to affect downstream flows, and can do so while diverting various amounts of water. Conversely, the only way that well field operators can favorably impact streamflows is to reduce the diversion. Furthermore, since storage tanks in distribution systems typically only have hours to a few days of storage, the only ways to reduce the diversion from well fields is to first reduce water demands, or in some cases shift some of the pumping to another source. Therefore, for well fields, water demands must often first be reduced to achieve a pumping reduction, to in turn increase stream flows to achieve a flow goal, after some time lag.

Exceptions to the above are systems with both surface water and groundwater sources. Depending on the quantity of the combined supplies versus demands, withdrawals from the two types of sources may be able to be optimized to achieve supply or impact goals.

Public water supply systems with only groundwater sources must rely on demand management to be able to favorably impact surface-water flows. Industrial and agricultural diverters face similar issues, although they typically have direct control over the demands. Demand management is included in Water Conservation Plans of the water utilities. In addition, wells covered by diversion permits often have low-flow or summer season reductions to reduce impacts on surface water. However, unless new sources can be developed, groundwater-based water utilities that currently have permitted wells without restrictions or registered wells cannot arbitrarily reduce pumping for the purpose of achieving a streamflow goal, unless they can shift the location of the pumping and/or successfully achieve demand reductions. Therefore, maintaining a good demand management program is essential for these utilities for them to be able to favorably affect streamflows when necessary. Even with a good demand management program, it may not be possible for existing groundwater-based systems to reduce demands sufficiently to achieve streamflow goals.

Flow Reduction Triggers During Drought

Nothing in these recommendations should be interpreted to require that outflows should be augmented to levels above inflows to a project. When the inflow upstream of a diversion project falls below any future established downstream release requirements, outflow will not exceed inflow. However, flow release reductions based on established triggers (see Section V) will allow outflow to be less than inflow to ensure adequate water supply during drought.

In order to maintain an acceptable water supply during drought, triggers or steps must be imposed to reduce the in-stream flow releases from reservoirs in order to ensure enough water is available to get through the remaining dry period. Since the duration of dry weather is unpredictable, the first step should be taken when reservoir levels start to indicate a drought and further steps to conserve water should be taken as the drought continues. There are a number of triggers that need to be investigated to determine which is the best one to support the goal of preserving the water supply during times of drought and not unnecessarily reducing in-stream flow releases. These potential triggers are: Streamflow forecasting and linking reservoir storage to in-stream flow release cut backs

In times of dry weather all users should share the burden of the reduction of available water. Water suppliers have drought contingency plans in place that spell out the actions to be taken when water supplies fall to below normal levels. Other users should develop similar plans if they do not already have them. When a water supply starts to enter the stages of its drought plan that call for various conservation measures, stream flow releases goals should be lowered as well. (Note: Some of the Subcommittee are not comfortable with this statement and would not support changing flow release requirements until it was clear water utilities had made every reasonable effort at conservation as described in their drought plans.) Flow release cut back triggers need to be established before any interim or long term instream flow benchmarks are put in place. There are a number of triggers that need to be investigated to determine which is the best one to support the goal of preserving the water supply during times of drought and not unnecessarily reducing in-stream flow releases. Some potential methods include:

a) Streamflow forecasting using historical flow data in a computer model. Using the model, long-term simulations can also be made to test operating policies such as reductions of in-stream releases, reductions in demand due to conservation measures and the conditions that trigger them. Multiple simulations can be run over the period of the hydrological record to develop appropriate triggers.

b) Streamflow forecasting using the Extended Streamflow Prediction System (ESP) which is conducted by the National Weather Service. ESP uses conceptual hydrologic/hydraulic models to forecast future streamflow using the current soil moisture, river and reservoir conditions with historical meteorological data. ESP produces a probabilistic forecast for each streamflow variable of interest (e.g., maximum flow, minimum flow, volume of flow, reservoir stage).

c) Linking reservoir storage to in-stream flow release cut backs could be piggybacked onto the conservation measures implemented in each individual water utilities drought contingency plan. When a water supply starts to enter the stages of its water supply plan which call for various actions the goals for stream flow releases could be lowered as well. The following is an example of how streamflow releases could be reduced to coincide with the stages of a water supplier's Drought Contingency Plan.

Drought Contingency Stage	Instream Flow release goal

Above Water Supply Alert	Lesser of inflow or flow target*
Water Supply Alert Stage	x^{th} percent of flow target *
Water Supply Advisory Stage	x^{th} percent of flow target *
Water Supply Emergency Phase I	x^{th} percent of flow target *
Water Supply Emergency Phase II	x^{th} percent of flow target *
Water Supply Emergency Phase III	x^{th} percent of flow target *

* Values to be determined by the individual water supplier

Development Impacts on Flow

Imperviousness has resulted in losses of groundwater and surface water supplies in more developed areas. This occurs as stormwater runoff is generated from newly impervious areas that once filtered groundwater recharge. Imperviousness can effect the hydrologic cycle in some areas, with groundwater recharge interrupted and streamflow and groundwater levels affected. At the same time, while centralized sewer systems have sometimes helped water systems overcome groundwater pollution, they can also impact water availability by diverting groundwater flow unintentionally via inflow/infiltration into sewers and intentionally via the direct export of sewage out of a given basin. Combined with losses from imperviousness, the result may be a significant decline in the availability of groundwater and surface water for water supplies in the future.

The WPC should consider and quantify other demands and losses to streamflows and make efforts to reduce these losses. Additional efforts should be put to re-establishing hydrologic cycles in developed areas. State agencies and all water supply professionals should vigorously advocate stormwater and wastewater management systems that preserve and restore a more natural hydrologic cycle, particularly groundwater recharge, with adequate pretreatment/treatment when needed to protect water quality (adapted from NEWWA White Paper, 2002). Development site design techniques that minimize impervious surfaces, promote groundwater recharge and preserve stream buffers should be incorporated into the state and local planning process.

Water Quantity Goals Framework

The following is a potential framework developed by the Subcommittee for establishing water quantity goals as guidelines for implementation of both the interim and long-term flow estimation methods:

A Conceptual Framework For Establishing Water Quantity Goals For Connecticut Rivers And Streams

Water Quantity Goals:

Category 1 - "Naturally flowing streams" – recognized for their unique ecological, recreational, aesthetic or social importance. These are currently unregulated streams for which free flowing habitat conditions shall be maintained and a high degree of protection is warranted.

Adopt interim instream flow prescription wherein outflow equals inflow.

Category 2 - "Nearly free flowing streams" - support natural ecological functions, riverine communities, and recreational uses. These streams are expected to support aquatic communities near to what would be expected if the system was unaffected by anthropogenic flow alterations.

Adopt interim instream flow prescription wherein outflow equals the daily target or inflow, whichever is less.

Category 3 - "Flow-altered streams" – riverine habitat has been altered by human use, including upstream diversions for public water supply, agriculture, and industry; thus the aquatic communities and recreational uses supported may differ from Category 2. The long-term goal for these streams shall be to restore riverine habitat conditions and flow regimes to Category 2 in consideration of existing uses and available water allocation options. However, this category also includes streams that normally meet the interim instream flow prescription but may periodically be subject to flow reductions to meet public water supply demands during drought conditions. As such, it is recognized that achieving the long term goal for some streams will depend upon the viability of alternate water supply and/or ecological management measures such as water supply operational changes, use of alternative water supplies, water demand reductions, instream habitat modifications, watershed management measures or some combination thereof.

Adopt interim instream flow prescription wherein outflow equals the daily target or X percent of inflow, whichever is less. Where appropriate, X may be adjusted downward to account for water supply needs.

Category 4 - "Flow impaired streams" – riverine habitat and ability to support recreational uses has been impaired by human use, including upstream diversions for public water supply, agriculture, and industry. The long-term goal for these streams shall be to restore riverine habitat conditions and flow regimes to Category 3 or higher in consideration of existing uses and available water allocation options.

Adopt interim instream flow prescription wherein outflow fails to meet the Category 3 criteria.

VI. Management Recommendations

The Subcommittee recommends implementation of a number of management approaches to ensure the sustainability of the region's water supply, while restoring flows needed to preserve and protect aquatic life.

a) Adaptive Management - Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form–"active" adaptive management–employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed. (From the Ministry of Forests, Forest Practices Branch of British Columbia Canada (http://www.for.gov.bc.ca/hfp/amhome/Amdefs.htm)
Discussed in detail in: Challenges in adaptive management of riparian and coastal ecosystemsWalters, C. 1997.

Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology [online]1(2):1. Available from the Internet. URL: http://www.consecol.org/vol1/iss2/art1

b) Water conservation as a "source" of water in lieu of new or proposed sources;

c) Mandatory water use restrictions and other adaptive/demand management measures, based on flow triggers, to protect both water supply capacity and natural resources during low-flow periods;

d) Optimizing the rate and timing of withdrawals from multiple sources and using storage where available to balance water supply needs with riverine ecological needs.

e) Increased infiltration of stormwater through use of Best Management Practices to improve recharge ratios for new development and retrofitting of existing development to improve groundwater recharge while protecting water quality;

f) The use of short-term "pulsed" releases should be evaluated as an alternative to continuous releases to reduce the impact of releases on water supply capacity while still providing downstream habitat benefit.

g) A provision to include flushing flows for channel and riverine habitat maintenance purposes should be considered on a watershed by watershed approach.

References

Apse, C.D. 2000. Instream flow protection in New England: Status, critique, and new approaches to standard-setting. Masters Thesis., Yale School of Forestry and Environmental Studies. 112 pgs.

Armstrong DS, TA Richards, and GW Parker. 2001. Assessment of habitat, fish communities, and streamflow requirements for habitat protection, Ipswich River, Massachusetts, 1998-99. U.S. Geological Survey. Water-Resources Investigations Report 01-4161. Northborough, Massachusetts. 72pgs.

Bain M.B. and Meixler M.S., 2000. Defining a target fish community for planning and evaluating enhancement of the Quinebaug River in Massachusetts and Connecticut. For the Quinebaug River Instream Flow Study Agencies.

Crawford, N.H. and R.K. Linsley (1966), *Digital Simulation in Hydrology: Stanford Watershed Model IV,* Stanford University, Department of Civil Engineering Technical Report 39.

CT DEP. 2000. Report to the General Assembly on State Water Allocation Policies Pursuant to Public Act 98-224. Connecticut Department of Environmental Protection. Inland Water Resources Division. Hartford, CT. 39 pgs. plus Appendices.

Fennessey, NM. 1994. A hydro-climatological model of daily streamflow in the Northeast United States. Ph.D. Thesis, Tufts University.

Fennessey, N.M. (2002), *The Sensitivity of Reservoir Firm Yield to Instream Flow Rules*, HYSR Presentation to Conn. WPC Committee, June

Fennessey, N.M. (2002), *The Sensitivity of Reservoir Firm Yield to Instream Flow Rules*, HYSR Presentation to Conn. WPC Committee, June 13, 2002.

Fennessey, N.M. (2002), *Estimating Flows on Ungauged Streams in the Northeast U.S.* , HYSR Presentation to Conn. WPC Committee, May 30, 2002.

Fennessey, N.M. and R.M. Vogel (1996), *Regional Models of Potential Evaporation and Reference Evapotranspiration in the Northeast U.S.A*., J. of Hydrology, Vol. 184, pp. 337-354.

Fennessey, N.M. (1995), *The Sensitivity of Reservoir Yield in Massachusetts to Model Time Step and Surface Moisture Fluxes*, ASCE J. of Water Resources Planning and Management, Vol. 121, No. 4, pp. 310-317.

Fennessey, N.M., A Hydro-climatological Model of Daily Streamflow in the Northeast United States, Ph.D. Thesis, Tufts University, August, 1994.

Fennessey, N.M. and P.H. Kirshen (1994), *Evaporation and Evapotranspiration Under Climate Change in New England*, ASCE J. of Water Resources Planning and Management, Vol. 120, No. 1, pp. 48-70.

Fennessey, N.M. and R.M. Vogel (1990*), Regional Flow-duration Curves for Ungauged Sites in Massachusetts*, ASCE J. of Water Resources Planning and Management, Vol. 116, No. 4, pp. 530-549.

Instream Flow Council,. 2002. Instream Flows for Riverine Resource Stewardship.

Karr, J. R., and D. R. Dudley. 1981. Ecological perspective on water quality goals. Environmental Management 5:55-68.

Kirshen, P.H. and N.M. Fennessey (1994), *Possible Climate-change Impacts on Water Supply of Metropolitan Boston*, ASCE J. of Water Resources Planning and Management, Vol. 121, No. 1, pp. 61-70.

Lang V. 1999. Questions and answers on the New England Flow Policy.USFWS, Concord, NH.

Larson HN. 1981. New England flow policy. Memorandum, interim regional policy for New England stream flow recommendations. USFWS, Newton Corner, Massachusetts.

MacBroom, J. 1983. Impact of Minimum Stream Flow Releases at MDC Reservoirs. Unpublished report. Flaherty Giavara Associates, New Haven, Connecticut.
Nehring,RB. 1979. Evaluation of instream flow methods and determination of water quantity needs for streams in the State of Colorado: Fort Collins, Colorado.

Nelson FA. 1984. Guidelines for using the wetted perimeter (WETP) computer program of the Montana Department of Fish, Wildlife and Parks: Bozeman, Montana.

New England Water Works Association (EWWA). 1974. History of New England Water Works Association. Boston, Massachusetts.

Parasiewicz P. 2001, MesoHABSIM: A concept for application of instream flow models in river restoration planning. Fisheries, Vol.26, No. 9

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, and others. 1997. That natural flow regime: A paradigm for river conservation and restoration. Bioscience 47(11):769-784

Richter BD, Baumgartner JV, Powell J and Bruan DP. 1996 A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10: 1163-1174.

Slack, J.R. and J.M. Landwher (1992), *Hydro-Climatic Data Network (HCDN): A U.S. Geological Survey streamflow data set for the United States for the study of climate variations, 1874-1988.* U.S. Geological Survey Open File Report 92-129.

Stalnaker C., et al. 1994 The Instream Flow Incremental Methodology: A Primer for IFIM

Soule, R. 1969. Discussion in the Journal of the New England Water Works Association, Boston, Massachusetts.
Tennant DL. 1976. Instream flow regimens for fish, wildlife, recreation and related environmental resources. Fisheries 1(4): 6-10.

Viessman, W. and G.L. Lewis (1996), *Introduction to Hydrology*, 4th edition, Harper-Collins Publishers.

Whittaker D and Shelby B. 2000. Managed flow regimes and resource values: traditional versus alternative strategies. Rivers 7(3): 233-244.

GLOSSARY OF INSTREAM FLOW TERMINOLOGY

ADAPTIVE MANAGEMENT - A process whereby management decisions can be changed or adjusted based on additional biological, physical or socioeconomic information (Instream Flow Council 2002)

AVAILABLE WATER. The maximum amount of water a company can dependably supply, taking into account the following reductions applied to safe yield: any limitations imposed by hydraulics, treatment, well pump capabilities, reductions of well yield due to clogging that can be corrected with redevelopment, transmission mains, permit conditions, source construction limitations, approval limitations, or operational considerations; and the safe yield of active sources and water supplied according to contract, provided that the contract is not subject to cancellation or suspension and assures the availability of water throughout a period of drought and that the supply is reliable. (CT State Regulations Sec.. 25-32d-1a)

BANK FULL FLOW. A high flow that is the dominant channel-forming flow. It has an approximate return interval of 1.5 years in a large variety of rivers.

BASE FLOW. The proportion of stream flow provided by groundwater (*i.e*., independent of surface run-off). Most of the stream flow during low flow periods.

CFSM. Cubic feet per second per square mile of drainage area. An extrapolation used to derive a flow estimate for a point in a watershed for which no site-specific gauging data are available from another known reference point. It assumes that water source and run-off characteristics are reasonably similar between the two basins.

CUBIC FEET PER SECOND (CFS). A volumetric measure of the rate of flow preferred by hydrologists. One CFS equals approximately 488.8 gallons per minute (GPM), 0.6463 million gallons per day (MGD). GPM and MGD are units preferred by water consumption engineers.

FLOW DEMONSTRATION METHOD(S). An array of incremental methods that enable a group of individuals to site-specifically assess the suitability of flows based on empirical observations and /or limited data collection rather than modeling. Typically this is used in lieu of modeling to settle a specific issue where modeling is impractical, too costly or relatively simple, and where a relatively precise, quantitative analysis is not required. Specific methods vary, but have been referred as "Delphi", BOBSAR, etc. and may rely on professional judgement and consensus of participants.

FLOW DURATION. The probability or likelihood that a flow rate is equaled or exceeded relative to some reference flow rate for some specific timescale, such as daily, weekly, monthly or yearly. For example, the 50th percentile flow, Q50, corresponds to the median flow, that which is equaled or exceeded half the time, and the reference for which flows are less, half the time. The 25th percentile, Q25, is the reference flow rate that is equaled or exceeded 25 percent of the time and flows are less than 75% of the time. Q99, an extreme low-flow is virtually equal to 7Q10 in the northeast U.S.

HABITAT SUITABILITY. The quality of a specific set of physical conditions relative to its targeted habitat function. In a stream flow context, this can be a function of quantity and duration of flow relative to the prevailing channel characteristics.

HABITAT SUITABILITY INDEX (HSI). A quantitative scale that provides an objective basis to rate specific types of aquatic habitat use on a scale from 0.0 to 1.0. These scales are applied to measurable physical stream characteristics (such as depth, velocity and wetted substrate) that may change relative to flow, and are specific to individual species and lifestages. The scales are generally based on observations of the frequency at which each species and lifestage selects each parameter under a given set of conditions.

IFIM. Instream Flow Incremental Methodology. An incremental analytical approach developed by the U.S. Fish and Wildlife Service to relate flow and habitat suitability for fish and aquatic life. Any technique in which alternatives for competing water use demands are objectively and iteratively analyzed at flow increments across a spectrum of possible flow alternatives is an IFIM analysis. This approach is frequently supported by computer-based habitat (PHABSIM) and hydrologic models when relatively small increments and precise estimates are required, although PHABSIM is not a prerequisite for an IFIM analysis.

INDICATORS OF HYDRAULIC ALTERATION (IHA). A suite of biological and physical parameters developed by the Nature Conservancy that may serve as diagnostic indicators of human effects on hydrology (both high flow and low flow magnitude and frequency). Software-support.

MARGIN OF SAFETY - The unitless ratio of available water to demand. (CT State Regulations Sec.. 25-32d-1a)

MEDIAN. A measure of central tendency, it is the value that lies at a point where 50 percent of the observations are above and below this value, regardless of the overall range. This is frequently preferred by hydrologists as a better way to characterize monthly flows over the mean (or “average”), which can be biased by extreme event outliers.

MESOHABSIM. A recent enhancement of PHABSIM modeling, in which the flow/discharge relationships found in key habitat types (riffle, run, pool etc) recurring throughout the affected area are modeled and analyzed in relationship to a targeted fish community associated with applicable habitat types. It indexes habitat change through both WUA as well as Fish Community Affinity.

NATURAL FLOW. A flow regime that is consistent with seasonal and annual variations for analogous Connecticut streams with no anthropogenic flow regulation. The meaning of the word "natural" is not limited to only those conditions which would exist in water draining from pristine land. Conditions which exist in the water, in part due to normal uses of the land,may be considered natural.

PHABSIM. (*Physical Habitat SIMulation Model*). PHABSIM was developed to support IFIM analyses. It is a computer-based habitat model that quantitatively and site-specifically rates the habitat suitability at increments across a range of specific flows of interest for specific species and life states and stream channels. PHABSIM incorporates a family of hydraulic and biological models that use depth, velocity and substrate/cover field data combined with species/lifestage-specific habitat suitability criteria to establish curves depicting aquatic habitat suitability across a range of flows. It produces areal estimates of habitat suitability known as WUA (see above).

REGULATED FLOW. The natural flow of a stream that has been artificially modified by reservoirs, diversions, or other works of humans to achieve a specified purpose or objective. *(From IFC 2002)*

SAFE YIELD. The maximum dependable quantity of water per unit of time which may flow or be pumped continuously from a source of supply during a critical dry period without onsideration of available water limitations. (CT State Regulations Sec.. 25-32d-1a)

7Q10. An index of low streamflow, used for wastewater treatment plant design studies. An annual statistic, it is an estimate of the lowest 7 consecutive days for flow that is expected to occur once every ten years, on average. It has no direct bearing on habitat suitability.

STREAM FLOW. Flow contained in a stream comprised of both base flow and run-off.

WETTED AREA. 1. The wetted width multiplied by a given linear upstream/downstream distance.

WETTED PERIMETER. The length of a stream bed circumference surface (in cross-section) wetted by stream flow.

WEIGHTED USABLE AREA (WUA): Quantitative habitat output generated by a PHABSIM (see below) analysis used to quantify changes in habitat suitability across a range of flow increments. WUA is that proportion of the calculated wetted area that is considered to provide the targeted species and lifestage with optimal habitat at any given flow.

WETTED WIDTH. The horizontal distance from one stream bank to another (in cross-section) wetted by stream flow.

Table 1. Watershed characteristics of "unregulated" Connecticut rivers with long term flow records (Apse, 2000).

River	Gage #	Watershed Area (mi^2)	Period of Record	Regulation	Stratified Drift	Physiographic Region
Ten Mile River	01200000	203	1931-99	Infrequent at low flows	18.1%	Western Highlands
Burlington Brook	01188000	4.1	1932-99	Occasional at low flows	33.2%	Connecticut Lowlands
Saugatuck River	01208990	21.0	1965-99	None	16.4%	Coastal Lowlands
Hubbard River	01187300	19.9	1939-99	None	0%	Connecticut Lowlands
Mt. Hope River	01121000	28.6	1941-99	Occasional by ponds	4.2%	Eastern Highlands
Salmon Creek	01199050	29.4	1962-99	None	16.4%	Western Highlands
Little River	01123000	30.0	1952-99	None	17.4%	Eastern Highlands
Salmon River	01193500	100.0	1929-99	Slight at low flows	14.5%	Connecticut Lowlands
Pendleton Hill Brook	01118300	4.02	1959-99	None	7.5%	Coastal Lowlands
Sasco Brook	01208950	7.38	1965-99	None	1.9%	Coastal Lowlands

Table 2. Monthly interim target flow alternatives for Connecticut rivers and streams in cubic feet per second per square mile (cfm).

	Median of the mean daily flows1	Apse's Recommendation2
October	0.45	0.45
November	1.14	1.14
December	1.52	1.52
January	1.53	1.53
February	1.77	1.77
March	2.60	2.60
April	2.54	2.54
May	1.63	1.63
June	0.77	0.77
July	0.33	0.51
August	0.23	0.37
September	0.22	0.38

1 Values from Table 4 in Apse (2000).
2 Values from Table 7 in Apse (2000). Apse recommends the median of the mean monthly flows for July through September (exceedance probability quantile ≅Q40), and the median of the mean daily flows for the remainder of the year (Q50).

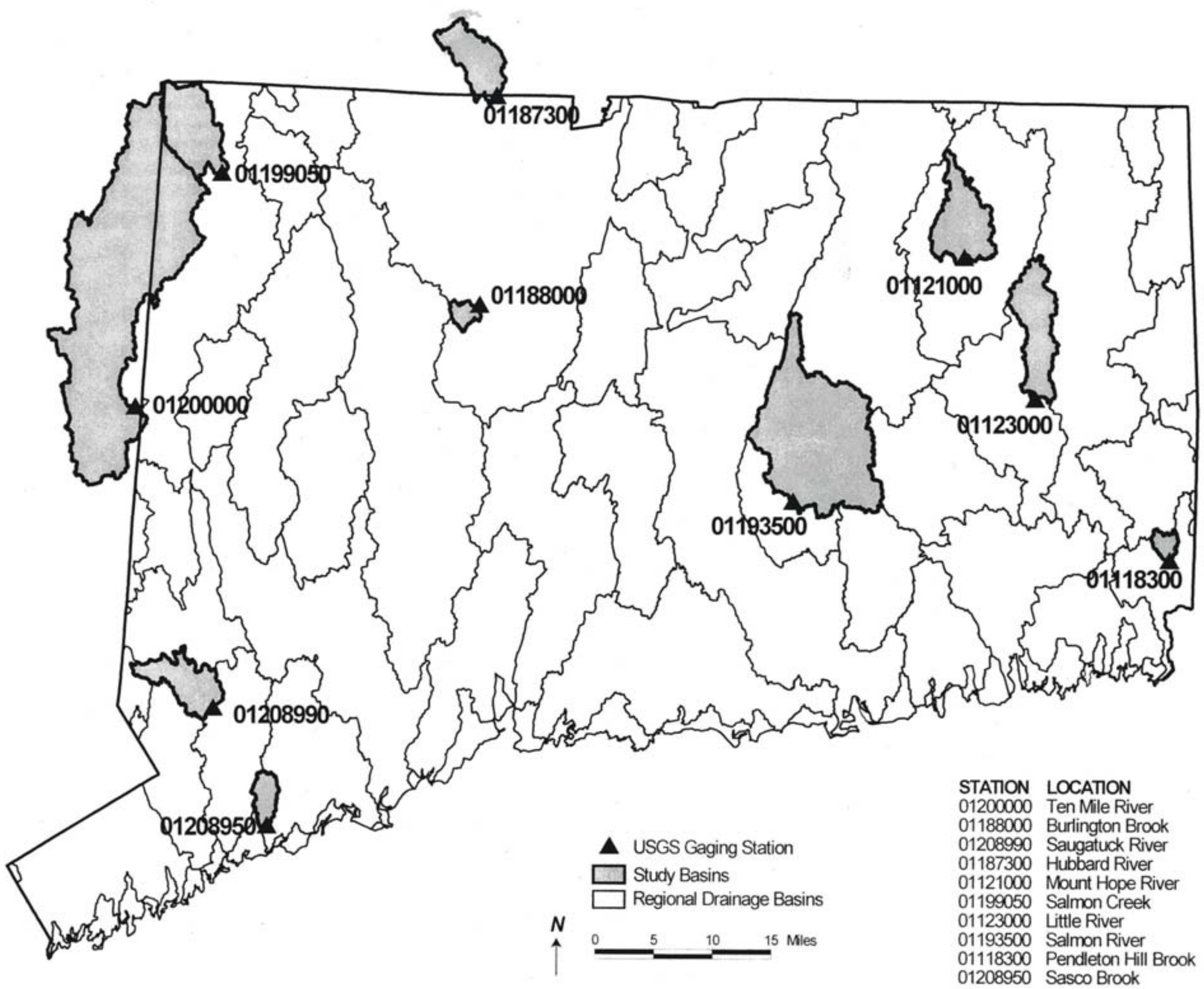
Table 3. Median monthly flows (cfm) and the corresponding exceedance probability as calculated by the FWS ABF method. Developed in part from Table 5 in Apse (2000). Exceedance probabilities were extracted or interpolated from the spreadsheets developed by Virginia deLima (USGS) and transferred via E-mail message dated July 31, 2002).

	ABF Calculation in cfsm (% duration flow)											
	Ten Mile River	Burlington Brook	Saugatuck River	Hubbard River	Mt Hope River	Salmon Creek	Little River	Salmon River	Pendleton Hill Brook	Sasco Brook	Mean	Median
October	0.35 (46)	0.83 (38)	0.50 (47)	0.61 (40)	0.61 (37)	0.67 (50)	0.65 (43)	0.60 (38)	0.68 (40)	0.72 (30)	0.62 (41)	0.63
November	0.94 (43)	1.82 (32)	1.53 (38)	1.76 (34)	1.39 (37)	1.40 (40)	1.49 (38)	1.31 (40)	1.58 (42)	1.30 (40)	1.45 (42)	1.45
December	1.50 (41)	1.95 (32)	2.41 (40)	2.18 (30)	1.83 (40)	1.50 (45)	1.91 (42)	1.85 (40)	2.33 (44)	2.07 (38)	1.95 (39)	1.93
January	1.39 (45)	1.90 (31)	2.18 (38)	1.65 (31)	2.24 (31)	1.70 (32)	2.43 (31)	2.35 (33)	2.85 (33)	2.08 (36)	2.08 (34)	2.21
February	1.70 (38)	1.99 (34)	2.65 (34)	1.65 (34)	2.38 (36)	1.61 (40)	2.57 (33)	2.40 (37)	3.16 (34)	2.19 (38)	2.23 (36)	2.29
March	2.96 (38)	3.85 (30)	3.23 (40)	3.25 (40)	3.55 (34)	2.72 (40)	3.47 (32)	3.62 (34)	3.79 (38)	3.04 (34)	3.35 (36)	3.36
April	2.79 (47)	3.53 (33)	3.04 (37)	4.17 (38)	3.01 (37)	3.08 (38)	3.16 (34)	3.24 (36)	3.55 (36)	3.02 (28)	3.26 (36)	3.12
May	1.62 (43)	2.27 (34)	1.85 (42)	2.43 (30)	2.15 (32)	1.96 (36)	2.12 (36)	2.14 (38)	2.36 (40)	1.82 (38)	2.07 (37)	2.13
June	0.81 (45)	1.17 (37)	0.80 (45)	0.91 (34)	0.78 (45)	0.98 (44)	0.99 (41)	0.93 (43)	1.09 (43)	0.66 (47)	0.91 (42)	0.92
July	0.53 (38)	0.74 (34)	0.49 (34)	0.38 (33)	0.43 (32)	0.68 (36)	0.59 (34)	0.45 (38)	0.51 (35)	0.34 (37)	0.51 (35)	0.50
August	0.31 (40)	0.55 (39)	0.39 (34)	0.24 (34)	0.31 (34)	0.43 (49)	0.44 (37)	0.34 (36)	0.28 (42)	0.39 (30)	0.37 (38)	0.37
September	0.28 (40)	0.59 (34)	0.31 (36)	0.27 (38)	0.25 (45)	0.55 (40)	0.44 (34)	0.36 (36)	0.32 (36)	0.38 (30)	0.38 (37)	0.34

Table 4. Flow statistics for “unregulated” Connecticut rivers with long term flow records. Includes median of mean daily flows for all months and the median of mean monthly flows (or FWS ABF method) in boldface type for July through September. All flows in cfm (derived from Tables 4 and 5 in Apse, 2000).

	Ten Mile River	Burlington Brook	Saugatuck River	Hubbard River	Mt Hope River	Salmon Creek	Little River	Salmon River	Pendleton Hill Brook	Sasco Brook
October	0.31	0.62	0.45	0.40	0.45	0.65	0.53	0.42	0.52	0.45
November	0.79	1.22	1.14	1.26	1.01	1.19	1.13	1.01	1.29	1.03
December	1.24	1.46	2.10	1.41	1.50	1.34	1.67	1.53	2.09	1.63
January	1.23	1.38	1.76	1.16	1.57	1.16	1.70	1.70	2.21	1.49
February	1.38	1.54	2.00	1.21	1.78	1.46	2.00	1.90	2.44	1.76
March	2.44	2.68	1.67	2.51	2.76	2.38	2.70	2.84	2.99	2.30
April	2.44	2.68	2.43	3.12	2.41	2.55	2.53	2.60	2.99	2.17
May	1.49	1.80	1.62	1.56	1.64	1.56	1.80	1.80	2.04	1.42
June	0.75	0.90	0.67	0.55	0.66	0.82	0.87	0.78	0.87	0.58
July	0.40 **0.53**	0.54 **0.74**	0.30 **0.49**	0.23 **0.38**	0.26 **0.43**	0.51 **0.68**	0.47 **0.59**	0.34 **0.45**	0.32 **0.51**	0.20 **0.34**
August	0.26 **0.31**	0.44 **0.55**	0.21 **0.39**	0.15 **0.24**	0.19 **0.31**	0.41 **0.43**	0.37 **0.44**	0.24 **0.34**	0.19 **0.28**	0.19 **0.39**
September	0.23 **0.28**	0.41 **0.59**	0.17 **0.31**	0.18 **0.27**	0.20 **0.25**	0.44 **0.55**	0.33 **0.44**	0.24 **0.36**	0.19 **0.32**	0.18 **0.38**

Figure 1. Geographic depiction of "unregulated" watersheds with long term flow records (Apse, 2000).



Appendix A - Water Allocation Task Force Report 7/2/02 Draft, Ecological Needs Section

ECOLOGICAL NEEDS - NEED FOR A CT INSTREAM FLOW STANDARD
- DRAFT VERSION (excerpt of sections 1 and 2)

Prepared by: James G. MacBroom, P.E., Milone & MacBroom, Inc. and Richard A. Jacobson, C.F.S., Department of Environmental Protection

1. INTRODUCTION

There has been an evolution in public expectations for environmental resources. With establishment of the federal Clean Water Act, the goal for all rivers has become ‘fishable and swimmable’ (is this Class B or higher?). In pursuing that goal, public and private resources were first directed at correcting water quality impairments and reducing waste discharges. Substantial progress has been made in the last 25 years, with many once highly polluted rivers now supporting a host of recreational uses. As the public’s use of these rivers expanded, so too did their interest in all rivers and the values they provide. At this point, it became apparent that many of the most pristine rivers were also exhibiting signs of aqautic habitat impairment - through diminishment of flow. As a result, managing water quantity as well as water quality, is recognized as essential in attaining the goal that all rivers are fishable and swimmable.

Concurrently, alterations in industrial water use and declining urban populations have reduced water supply demands in some large cities, while the growth of suburban and rural communities encourage expanded use of public water sources. In addition, the Safe Drinking Water Act and its surface water treatment requirements has led to the abandonment of small reservoirs, and encourages interconnections with large centralized water systems, and development of ground water supplies. Another factor which raises recent interest in streamflows at this time is the need for utilities to renew many Federal licenses for aging hydroelectric generating plants that regulate discharges.

The right to regulate streamflow was reinforced by a recent court case. On May 31, 1994, the U.S. Supreme Court ruled in a case involving the State of Washington that allows streamflow requirements to be included in the conditions of the Clean Water Act Section 401 Water Quality Certificates. The Court found regulating instreamflow consistent with protecting water quality (this may require further explanation/clarification).

2. RATIONALE FOR ESTABLISHING INSTREAM FLOW RATES

Stream flow rates have been altered by humans for thousands of years through diversion for out-of-stream uses (i.e., crop irrigation, livestock, mechanical and electrical energy, transportation, and water consumption). Streamflow modifications are generally due to dams that impound water for later use or diversions that withdraw water from the rivers and release it at a different time or place.

The ability of upstream water uses to alter downstream flow rates has historically led to conflicts and competition for water. Although the eastern United Sates has a humid climate with generous precipitation, water conflicts were common even in colonial periods. Many early riparian water laws (i.e. riparian rights) developed in response to resolving flow conflict at water powered mills located sequentially along rivers. Today, instream flow conflicts arise because of the need for diluting effluent, water supply diversions, recreational and commercial fishing, whitewater boating, tubing, and ecological impacts.

The early concept of having selected dam owners release a minimum flow into downstream channels had its origin in maintaining fisheries. Over time it has been recognized that fixed year-round minimum flow rates do not effectively meet downstream flow needs; seasonal variation is necessary to meet specific needs such as migration, sawning, and egg incubation. The concept of "variable flows" superseded the concept of "minimum flows" and a new term "instream flow" has been adopted to describe a flow used to meet time dependent needs.

Streamflow management involves many different water users and water related issues (see table below). Many water users that have an interest in streamflow rates have difficulty meeting all water demands.

Categories of Instream Flow Features:

Physical	Biological
water temperature dissolved oxygen effluent dilution effluent assimilation groundwater recharge sediment transport salinity intrusion aesthetics channel morphology bank stability substrate composition	migratory fish passage macroinvertebrate production juvenile fish development endangered species amphibians reproduction vegetation encroachment riparian wetlands fish egg incubation

Riparian law (Reis, 1967) distinguishes between consumptive and non-consumptive streamflow uses. The consumptive uses have a greater potential to impact downstream interests compared to non-consumptive users that return the full volume of water to the stream at or near the point of withdrawal although the return water may not be of the original quality. Riparian law established that riparian land owners may make reasonable diversions that can be beneficially used without causing undue injury to downstream areas (Reis, 1967). The right to divert for consumptive purpose exists under riparian law but is limited to reasonable use.

Streamflow Uses

Consumptive	Non-Consumptive	Recreational and	Aquatic

		Cultural	
Irrigation Livestock water supply off-site cooling water off-site washwater aquifer recharge water supply diversions	hydroelectric power hydromechanical power river navigation once-through cooling	aesthetics white water sports power boats swimming fishing tubing	invertebrates reptiles amphibians fish birds rooted aquatic plants algae plankton

Expanding land development in Connecticut and the dependency of urban areas on water sources in competition with other uses and users, has led to increased regulatory control over water diversions. The Connecticut Water Diversion Regulations and Water Utility Planning process both impose administrative procedures that attempt to define how riparian law dictates water allocation between competing uses, much as laws in western states define how prior appropriation doctrine do so there.

The administrative control of water diversions, and streamflow also address the rights of non-riparian persons and environmental concerns. This is a fundamental change in water resource management that has evolved over the past 20 years (Cox, 1994). The specific concerns about selected streamflow issues and users are noted below:

Water temperature - Low flow rates in streams lead to reduced flow depths and velocities, increased solar penetration, longer exposure and higher water temperatures. As water temperatures rise, cold water fishes, such as trout, are excluded and replaced by non-native cool and warmwater species.

Dissolved oxygen - Low flows have less turbulence and lower aeration rates. Warm waters have a reduced oxygen saturation level, lowering productivity of coldwater communities, and in extreme cases increased incidence of fish kills. For example, widespread stream fishkills occurred in Connecticut during the dry warm summer of 1993. Low oxygen levels are also associated with increased odor from decomposition of organics.

Effluent dilution - Wastewater treatment plants depend on a minimum flow at their outlets to dilute the effluent in a limited mixing zone to meet water quality standards.

Effluent assimilation - Wastewater treatment plants depend upon streamflows to biologically assimilate and renovate the effluent downstream of the outfall mixing zone. Excessively low flows can lead to water quality degradation.

Groundwater recharge - Some watercourses are located over pervious soils such as stratified drift and help to recharge aquifers via streambed infiltration. Excessively low flow can reduce recharge and reduce the yield of stream influenced water supply or irrigation wells.

Sediment transport and substrate composition - Watercourses with heavy sediment loads depend upon having sufficient flow to transport sediment. During periods of low flow, reduced velocities and water volumes limit sediment transport and encourage deposition in slack water areas. As a result, coarse substrates (e.g., cobble and gravel) are embedded with fine materials, rendering the substrates unsuitable for fish spawning, egg incubation and juvenile develop, and invertebrate production.

Channel morphometry - flows necessary to maintain channel shape and pool/riffle formation.

Salinity intrusion - Low flow rates and water levels in coastal rivers allow greater inland migration of high tides and salt waters. This becomes very serious if salt water reaches water supply inlets or wells. The water quality characteristics and coincident biota of estuaries changes with reductions in freshwater inputs.

Aesthetics - Streams and rivers are generally considered to have a positive visual appearance that is dependent upon having adequate water to cover the channel bed. Low flows expose the stream bed and debris, and encourage growth of undesirable plants.

Migratory fish passage - Low flow rates and shallow water limits the seasonal migration of both freshwater and anadromous fish, potentially interfering with spawning, juvenile development and adult movements.

Stocked fish - Many rivers are stocked with hatchery raised fish for recreational fishing. Artificially high fish populations in the critical summer months require adequate streamflow for shelter, water quality, and food sources.

Self-sustaining fish - Self-sustaining fish populations require adequate flow not only in the summer but also in the winter, to deter bottom ice over spawning areas and to maintain open water for aeration. In addition to migratory passage, self-sustaining populations require flow to deter ice formation, maintain channel morphometry and substrate characteristics, egg and juvenile development, and adult feeding and refuge.

Rare and endangered species - Water dependent rare and endangered species, such as fish, amphibians, and water fowl may be impacted by low flow rates that restrict their habitat, food, or shelter.

Vegetation encroachment - Sustained periods of low flow, particularly when combined with the regulation or absence of flood flows, allow terrestrial and wetland vegetation to encroach on the channel and become established on mid-channel bars. This then encourages further sediment deposition.

White water recreation - The rivers used for white water sports need to have sufficient flow to generally provide water depths of about two feet and channel widths of 25 feet. For many users, flow velocities over five feet per second should be avoided.

In order to minimize conflicts, it is important that the methodology used to establish instream flow rates be technically valid and have a high level of public confidence.

Appendix B – Summary of Interim Instream Flow Methods Reviewed

1. New England Aquatic Base Flow (ABF)

Developer: U.S. Fish and Wildlife Service (FWS), Region 5. It is a component of the broader U.S. Fish and Wildlife Service Interim New England Flow Policy (1981). The Flow Policy itself is an internal FWS directive that establishes standard procedures for FWS personnel when reviewing projects. The policy is structured to include both a reconnaissance-level approach (ABF) and site-specific approach (IFIM) for developing recommendations.

Summary: The term Aquatic Base Flow was coined by FWS to describe a set of chemical, physical and biological conditions that represent limiting conditions for aquatic life and wildlife in stream environments. In hydrological terms, it derives median August flow by taking the median of monthly mean flow from 48 unregulated gages across all of New England. Default values of 0.5 cfsm for August Median, 1.0 cfsm and 4.0 cfsm for spawning and incubation flows are used where adequate site specific gage data does not exist or a site specific study is not performed The ABF approach targets ABF as the pass-by flow "or inflow if less" to account for low flow excursions. The "Diversion 2000 Report" (CT DEP 2000) recommends use of ABF until a "Connecticut Aquatic Base Flow" methodology is developed.

Assumptions: ABF assumes, among other things, that August reflects the most limiting period during the summer low flow season as a consequence of the combined effect of low flows and high water temperatures. The median value reflects the ability of aquatic communities to withstand periods of lower flow if provided with the opportunity to recover during periods of higher flow.

Use in New England: Used by FWS in over 300 applications, primarily hydroelectric relicensing. Modification included in the Vermont Water Quality Standards, and used by the Maine Land Use Regulatory Commission. The ABF has been recommended in Connecticut, though diversion permit applicants have the option of conducting other appropriate studies to determine instream flow requirements.

Strengths: Quick and relatively easy to use. It is consistent and easy to understand. Several recent site-specific studies, including the Quinebaug River and Ipswich River (Armstrong et al. 2001) have shown positive relationship between ABF recommendations and aquatic life protection.

Limits and Constraints: (Extracted from IFC 2002) The ABF method does not directly consider geomorphology, biology, water quality, or connectivity, and it does not address the flow needs of specific species or life stages. It is not appropriate for negotiated decisions in which multiple alternatives are explored. Selection of the August median flow, as opposed to some other flow statistic (e.g., September median flow, August mean flow, 60% exceedence flow for July-September) is somewhat arbitrary. Some water users dispute the exact means for calculating gage statistics and, in turn, suggest alternative flow values. Altered watersheds will exhibit altered hydrographs, gage data, and medians.

2. Connecticut Minimum Flow Standards

Developer: Connecticut Department of Environmental Protection (DEP)

Summary: Connecticut's Minimum Stream Flow Standards established, in 1977, establish minimum flow standards and variance procedures for all fish-stocked river and stream systems. These regulations, found in Regulations of Connecticut State Agencies Section 26-141a, use a table to determine the required daily average releases from the impoundment based on the percent of safe yield utilized. For existing impoundments the regulation required releases of between 0.01 and 0.20 cubic feet per second per square mile of drainage area (cfsm). For new impoundments, the regulations specify releases of between 0.02 and 0.25 cfsm. In any event, these regulations require no more than one half of the August base flows recommended by the FWS ABF policy (Apse, 2000).

Assumptions: The biological/technical basis for the required releases is not clear.

Use in New England: Connecticut only.

Strengths:

Limits and Constraints: The instream flow standard applies to waterbodies that are designated as a stocked watercourse and tributaries to a stocked watercourse. There are few watercourses so designated and even these do not always have enforceable flow standards. Diversion or impoundment operators can be exempted from these regulations by petitioning the Commissioner of Environmental Protection. These regulations are seen by state agency staff as being difficult to implement and even more difficult to enforce. Additionally, the Minimum Stream Flow Standards do not address groundwater withdrawals.

3. Tennant Method

Developer: Donald Tennant, FWS, in Montana.

Summary: Based on percentages of average annual flow (AAF) derived from estimated or measured hydrologic records. Narrative descriptions of flow include flushing, optimum range of flow, outstanding, excellent or good habitat down to fair or poor habitat and severe degradation. Recommendations are given for April- September and October - March periods.

Assumptions: Various percentages of average annual flow are appropriate for maintaining habitat quality, that the time periods for providing different levels of flow are appropriate and if properly calibrated is transferable from the streams Tennant used to develop the method.

Use in New England:

Strengths: Low level of effort, however, field effort is required if the user desires to calibrate or adjust on a regional or site specific scale.

Limits and Constraints: (See IFC 2002) AAF developed from hydrologic data, thus recommendations are only as good as data. Developed for western streams; not tested in eastern waters. Where hydrologic records are simulated from other basins, ranges in confidence intervals arise. Average annual flow does not represent season patterns in hydrology.

4. Range of Variability Approach

Developer: The Nature Conservancy

Summary: This approach is an extension of the Nature Conservancy's Index of Hydrologic Alteration (IHA). Target streamflows are determined by identifying an appropriate range of variation in each of the IHA's 32 indicators.

Assumptions: That the full range of natural variability in the hydrologic regime is necessary to conserve aquatic ecosystems.

Use in New England: US Geological Survey (USGS), Ipswich river habitat assessment report (Armstrong et al. 2001)and Usequepaug-Queen River Rhode Island (in preparation), Massachusetts Stressed Basins Technique, various site specific studies.

Strengths: Allows managers to develop flow targets and river management strategies without long-term ecological data. Application requires that strategies and targets be revisited once ecological data have been collected and implemented.

Limits and Constraints: Availability of adequate streamflow records that limit applicability of all IHA parameters. Default statistical derivation of natural variability (mean plus or minus one standard deviation) may not work where hydrological data is not naturally distributed (e.g., highly altered flow regimes).

5. Wetted Perimeter Approach

Developer: Multiple developers including Nelsen (1984).

Summary: Wetted perimeter in riffles is graphed versus flow. Wetted perimeter is that distance along the stream bottom measured from the wetted edge on one side to the wetted edge on the other side. The "breakpoint" on the graph is the flow recommendation. Some applications use computer programs based on Manning's equation to compute the stage-discharge relation for a cross section.

Assumptions: Assumes that adequate habitat is provided by the flow that wets the channel bottom and begins to rise up the banks.

Use in New England: USGS Ipswich habitat assessment report (Armstrong et al. 2001) and Usequepaug-Queen River Rhode Island (in preparation). Maine DEP uses a modification of this approach for river macroinvertebrate protection.

Strengths: Relatively easy to measure. Useful if only "low" flow prescriptions are needed.

Limits and Constraints: Used primarily to develop a low flow standard (summer and fall) and does not address intra- or inter- annual variability. Several visits (10 or more) to site at different discharges are necessary if empirical relations are to be used. Fewer needed if computer simulations are developed.

6. R-2 Cross or Habitat Retention

Developer: Nehring (1979)

Summary: Habitat is assessed based on hydraulic criteria measured in critical areas of streams such as riffles. Stream flows required for habitat protection are determined from flows that meet criteria for three hydraulic parameters: mean depth, percent of bank full wetted perimeter and average velocity.

Assumptions: Assumes that a discharge chosen to maintain habitat in the riffle is sufficient to maintain fish habitat in nearby pools and runs for most life stages of fish and invertebrates

Use in New England: USGS Ipswich habitat assessment report (Armstrong et al. 2001) and Usequepaug-Queen River Rhode Island (in preparation).

Strengths: Relatively easy to measure. Requires site-specific data at one or more transects. Computer generated hydraulic characteristics are needed.

Limits and Constraints: Used primarily to develop a low flow standard (summer and fall) and does not address intra- or inter- annual variability.

7. Connecticut Aquatic Base Flow Method (Apse Method)

Developer: Colin Apse, Yale University

Summary: Uses a two tiered approach. Table 1 lists the 10 rivers and gauges used in the method, whereas Figure 1 shows the contributing watersheds to these gages.

Tier One: Uses a median of mean daily flows for each month for unregulated rivers throughout Connecticut. These values would apply on a monthly basis to all months except July, August and

September. The summer standard would be calculated from the median of mean monthly flow, averaged for all unregulated rivers in CT. <u>Tier Two</u> Allow and encourage water developers to adopt an alternative standard that incorporates natural variability. Potential include the percentage-based approach (Whittaker and Shelby, 2000), trigger flow method and RVA.

In addition, a provision to include flushing flows should be considered on a watershed by watershed approach. This could include several days of flows at 3.75 cfsm.

Assumptions: As this is a refinement of the FWS ABF approach (i.e. based on Connecticut hydrology statistics),it is implicit that biological assumptions mirror those of the FWS ABF . It assumes that Connecticut streams have hydrologic cycles that are identifiable and differ from other regions within New England. Assumes flow in gaged basins is truly natural.

Use in New England: none, as yet.

Strengths: Statistics are based on local watershed data.

Limits and Constraints: Median statistic not necessarily related to habitat suitability. The method does not address natural variability among streams in Connecticut.

[The following two techniques can be used to estimate daily flow statistics, which in turn can be used to estimate monthly flow statistics. These techniques can be applied to Step 2b of the interim method approach described in section III of the Subcommittee report entitled "Recommendation – Interim Method"].

8. QPPQ Transform Method

Developer: Fennessey (1994)

Summary: A procedure that generates daily streamflow at an ungaged site using data from flow in gaged, unregulated basins in the northeast. A regression approach that includes watershed variables such as main stream channel slope, watershed relief, precipitation, and soil-moisture retention.

Assumptions: Flow in the gaged basins is truly natural. The wide range in settings in the northeast will cover all possible situations in Connecticut.

Use in New England: Quinebaug River MesoHABSIM study, several studies in Massachusetts.

Strengths: Generates daily hydrograph, generates site-specific statistics; relatively simple to use.

Limits and Constraints: It is not clear that watershed conditions in the large northeast area(Pennsylvania to Maine) provide a reliable basis for determining flows for Connecticut streams.

9. Rainfall-Runoff Models

Developers: Stanford Watershed Model, Crawford and Linlsey (1966); National Weather Service River Forecast System model; Hydrocomp (Hydrological) Simulation Package FORTRAN (HSPF), Hydrocomp, Inc.

Summary: These models generate daily flow at ungaged sites by representing the passage of precipitation on the watershed through the soil layers and ultimately to the stream channel.

Assumptions: Most accurate estimates of flow in a steam are generated from data on that stream.

Use in New England: Connecticut River, Nashua River, and Ware River in Massachusetts (NWSRFS); Ipswich River in Massachusetts (HSPF).

Strengths: Uses features of the target basin to develop estimates of flow for that basin. Ability to vary parameters to generate natural (pre-anthropogenic influence) runoff. Incorporates water-quality modeling routines.

Limits and Constraints: Estimates of many parameters are required as input data making the procedure time consuming and costly.

Appendix C – Excerpts from Presentation of Piotr Parasiewicz on the MesoHABSIM Approach

Obviously, with our present tools, we are not able to measure all of the microhabitats in a given river. The common approach is therefore to sample microhabitats in selected sites, which is much more manageable, and then follow the above framework to generalize the results to the right scale.

There are two techniques used to extrapolate microhabitat information into larger units according to the above scheme.

The less-common approach of "mesohabitat typing" involves the measurement of hydraulics along cross-sections within hydromorphologic units such as riffles or pools. The proportions of hydromorphologic units in the reach are determined by detailed mapping or measurements taken at random. To define the character of the reach, the average habitat values calculated for sampled units are summarized proportionally. The same procedure is used to extrapolate the character of reaches into the segment scale, and so on.

The other method is called the "representative site approach" and is used much more often. It involves selecting a site that is "typical" for river reach, and assuming that the remaining part of the reach is similar to the selected site. This method is often abused, however; in an attempt to respond to the growing demands on watershed management techniques, the "reaches" become progressively longer and representative sites become shorter.

The attempts to use this method on the Quinnebaug River in Massachusetts and Connecticut were not successful due to the river's high level of variability. The change in physical characteristics that Quinebaug exhibits every few meters, indicated that to measure the river properly would require a great deal of effort. These difficulties proved to be pivotal in leading to the development of MesoHABSIM that led to the development of MesoHABSIM.

In actuality, MesoHABSIM is not drastically different from previous methods. Borrowing from the mesohabitat-typing approach, it shifts from precise hydraulic measurements and hydraulic modeling to mesohabitat mapping and multiple observations. The underlying goal of MesoHABSIM is to operate in a scale that has more biological than hydraulic justification. Many recent studies have demonstrated the high biological relevance of the mesohabitat scale. It has also been recognized that species composition within mesohabitats is very unique and there is a much greater difference in species abundance and composition between mesohabitats than there is between the microhabitats within these units.

We have also realized that although hydromorphological units form the shape and hydraulic character of mesohabitats, they alone cannot fully describe the habitat settings. To determine the mesohabitat conditions they need to be combined with other parameters that provide cover and shelter. In other words, one must recognize that a pool with woody debris can be a different mesohabitat than a pool without woody debris.

Appendix D – Water Supply Impacts Discussion

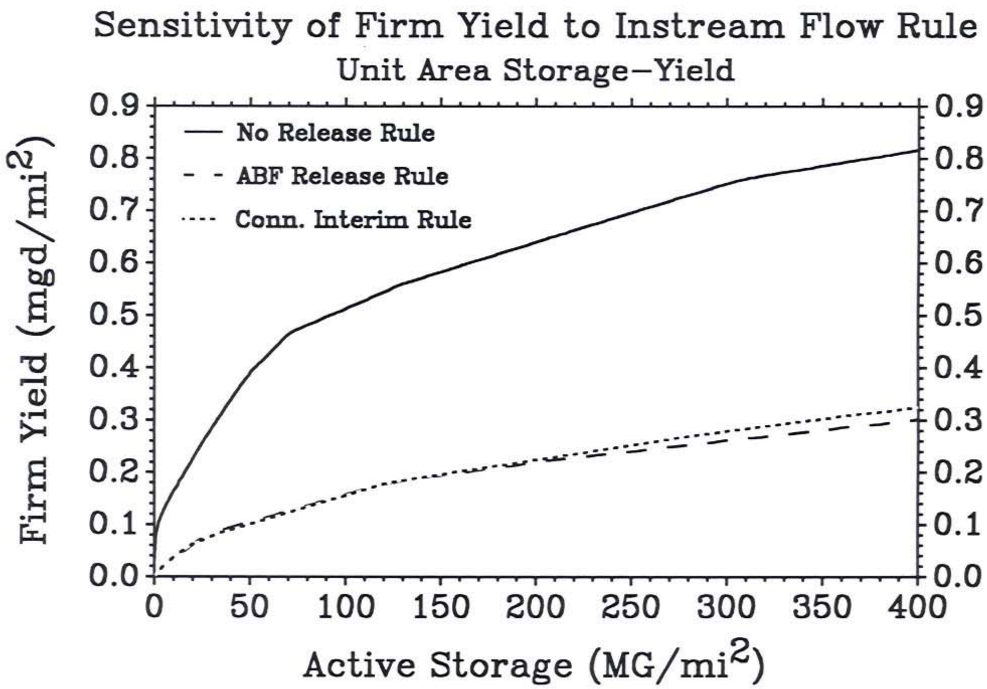
[NOTE: The following is an analysis of potential impacts to water supply only. Strategies to mitigate these potential impacts, as recommended by the Subcommittee include water conservation, effective demand side management, effective stormwater management, etc.]

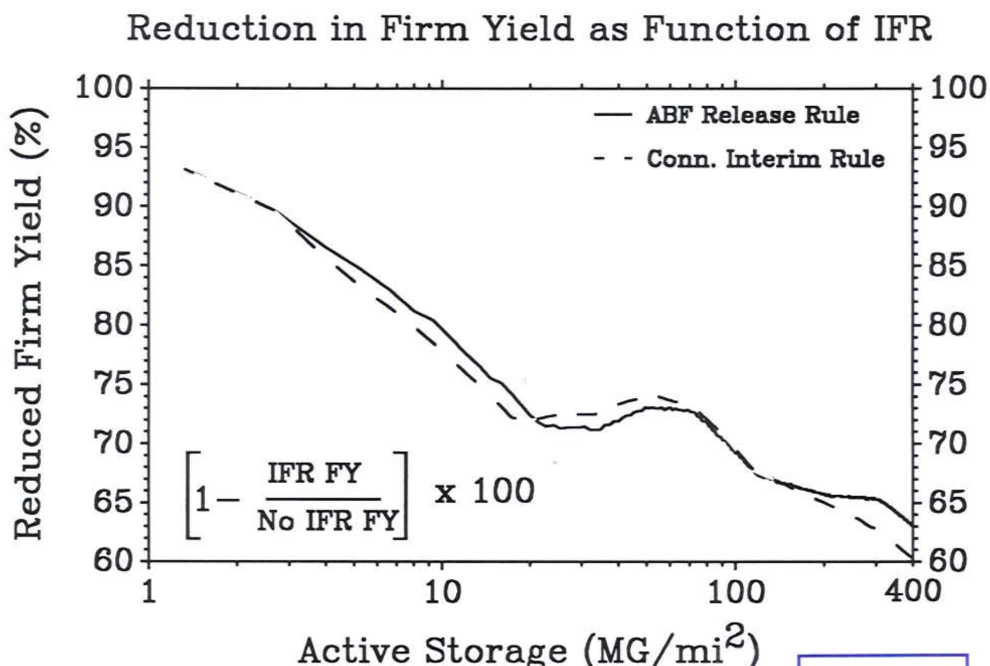
On June 13, 2002, Dr. Neil M. Fennessey (2002) presented the results of a computer simulation model assessment of the potential impact of the proposed inflows equal outflows instream flow operating rule (IFR). The rule is described in *III. Interim Instream Methods.* Applying the proposed monthly instream ecological flow goal statistic as the trigger for the IFR operationally is as follows. When the inflows upstream of a diversion fall below the monthly ecological flow goal rate, the project outflows (downstream releases) must equal the project inflows. When the project inflows exceed the monthly ecological flow goal rate, the project must release and/or spill at least this rate. For those diversions that are incapable of releasing water from storage, such as groundwater source systems, they would have to wait for the streamflow to rise above the monthly ecological goal rate before being allowed to turn on their pumps. Although highly protective of downstream uses, the potential impact on withdrawers would be significant.

Over a long period of time by statistical definition, a groundwater supply system would be required to cease withdrawing water at least half the time during the months of October-June if the Apse (2002) monthly statistics are used. During the months of July-September, these systems would be required to cease withdrawing water approximately sixty percent of the time (V. deLima, USGS, 2002, Apse median of monthly mean equivalent daily percentile estimates, daily Q40).

Dr. Fennessey showed the Committee that if a very small reservoir system was required to adopt the outflows equal inflows IFR, that reservoir's safe yield (a measure of reliability) would fall to 10% of what that reservoir would be rated for before adopting the proposed IFR. If a system with a very large reservoir was required to adopt the outflow equal to inflow IFR, that reservoir's safe yield would fall to 40% of what that reservoir would be rated for before adopting the proposed IFR. See Tables D-1.1 and D-1.2.

If either system's water use was equal to the safe yield, to operate with the same level of reliability, the small reservoir system users would need to cut their water usage by 90%. Similarly, the large reservoir users would have to cut their water usage by 60%. In order to maintain the same level of service and reliability, any system that could not trim water usage to this degree would be forced to build additional reservoirs or find alternative, additional sources of supply. Figure D-1 shows the results of Dr. Fennessey's computer simulation. The *Active Storage (MG/mi^2)* axis represents the volume of accessible water (million gallons) in a reservoir divided by its contributing watershed area (square miles). The *Firm Yield (mgd/mi^2)* axis represents the volume of water that can be withdrawn every day over a long period of time, divided by the source reservoir's contributing watershed area (million galls per day per square mile). The upper graph's curves illustrate that as the reservoir volume increases, the safe yield does too, but not in a straight-line (linear) fashion. The bottom graph curves show that the degree of reduction in safe yield is very large for small reservoir but not as great for large reservoirs. Table D-1 serves to summarize some of the information found in Figure D-1.





HYSR

Figure D-1. Sensitivity of Reservoir Yield to "Inflow Equals Outflow" Rule

Table D-1.1
Impact of Proposed "Inflow Equals Outflows" Rule on Water Supply Systems
Comparison Between Present and Future Safe Yield

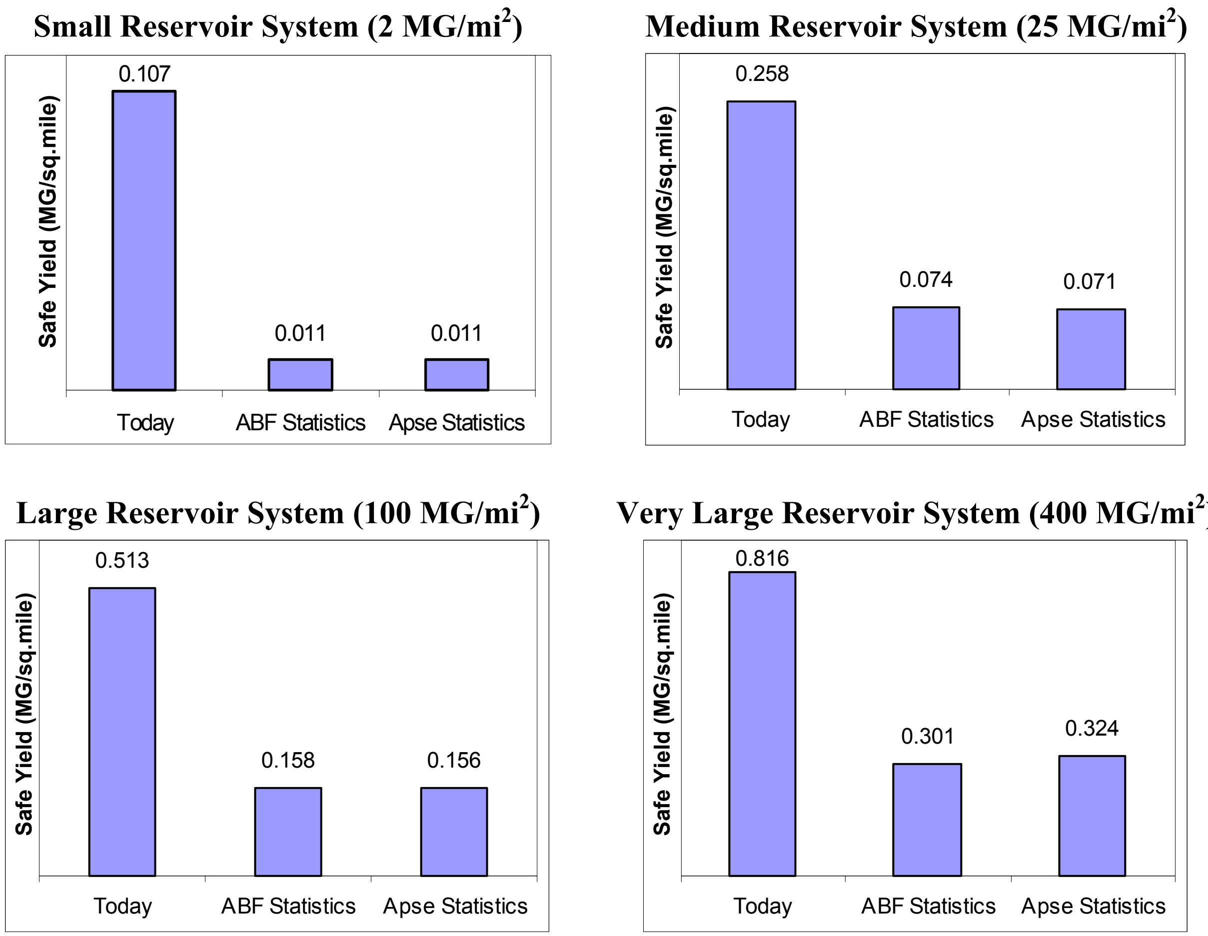
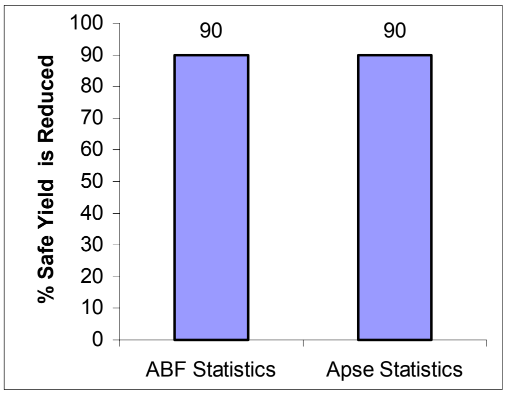
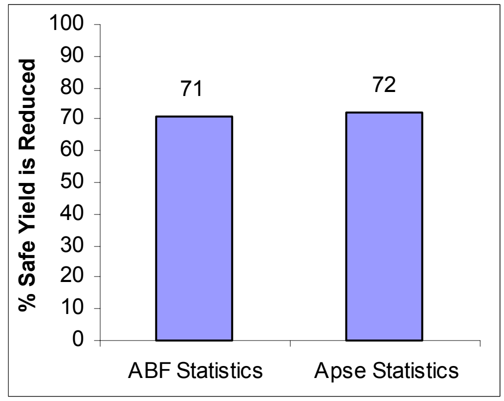


Table D-1.2
Impact of Proposed "Inflow Equals Outflows" Rule on Water Supply Systems
Percent Reduction in Safe Yield

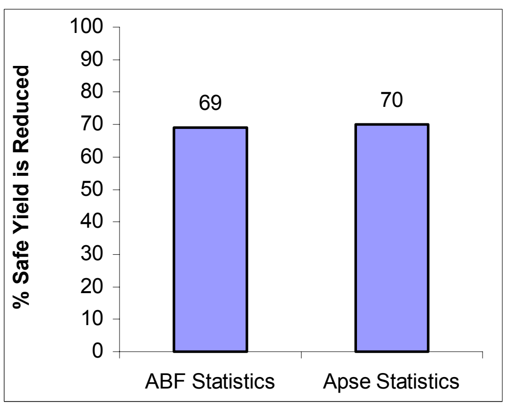
Small Reservoir System (2 MG/mi^2)



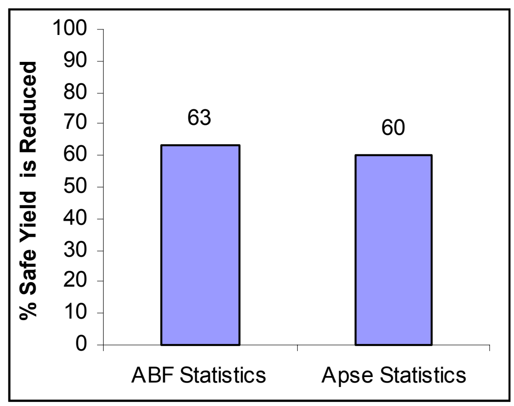
Medium Reservoir System (25 MG/mi^2)



Large Reservoir System (100 MG/mi^2)

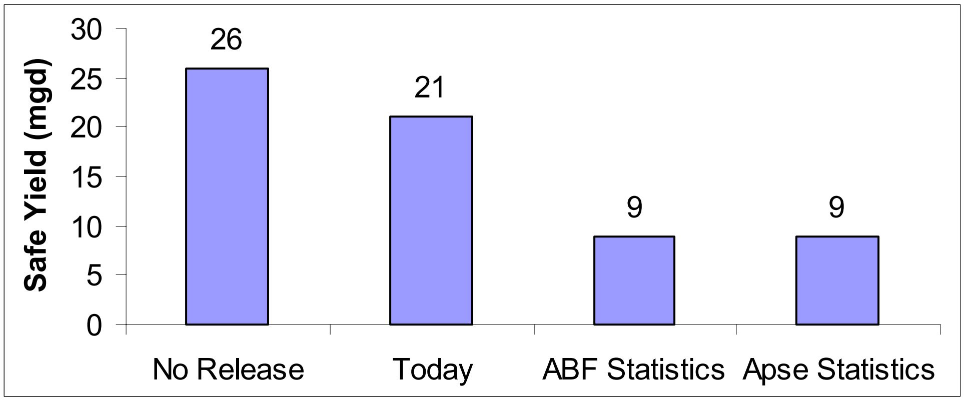


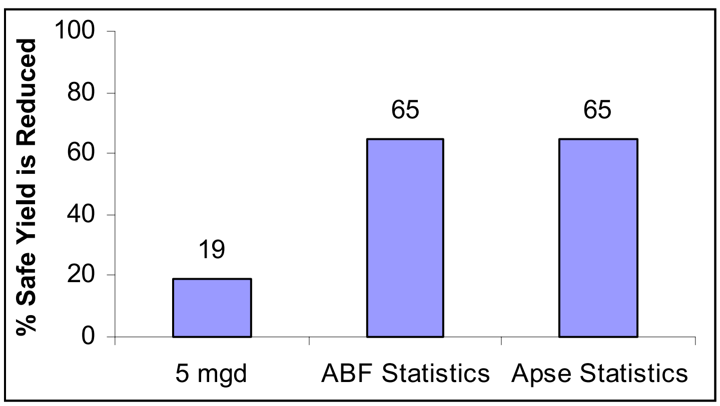
Very Large Reservoir System (400 MG/mi^2)



Dr. Dan Sheer incorporated the proposed IFR using the Apse (2000) monthly statistics into a computer simulation model of the city of Waterbury multi-reservoir water supply system. The current safe yield of Waterbury system (both the Shepaug River system and the Branch Brook system) drops from approximately 21 million gallons a day (including the current releases of up to 5 mgd (0.2 cfsm) made for the benefit of downstream users) to nine million gallons a day, which is seven million gallons below the system's current average annual daily demand of 16-17 mgd. The results are shown in Table D-2.

Table D-2
Impact of Proposed "Inflow Equals Outflows" Rule on City of Waterbury





These results support the Committee's recommendation that any proposed instream flow rule be fully tested through economic, mathematical and computer simulation before being considered for application as a standard.

[The following is excerpted from 7/2/02 Water Allocation Task Force Report Appendix A, Ecological Needs – Need for a CT Instream Flow Standard (MacBroom and Jacobson)]

> Implementation of minimum releases at reservoirs to maintain downstream flow rates, or increases in minimum release rates, can have a significant impact upon water supply safe yield and could increase the need for additional sources. Reservoirs in turn have a substantial impact on downstream aquatic ecology if they do not release adequate flows.
>
> For example, the often discussed release rate of 0.2 cubic feet per second per square mile of watershed area is equal to eleven percent of the mean annual runoff, and is larger that the

margin of safety (excess yield) of some water systems. The U.S. Fish and Wildlife Service recommended Aquatic Base Flow of 0.5 cfsm is 28 percent of the mean annual runoff rate.

Detailed studies were conducted of the potential impact of proposed stream flow releases upon the safe yield of the Hartford Metropolitan District Commission in the Farmington River Basin. A continuous simulation computer model was used to analyze the reservoir's safe yield with and without the additional streamflow release. It was found that the safe water supply yield of the 1960's drought period would be reduced by 12.1 percent (MacBroom 1983).

The potential water supply impact of instream flow releases is further highlighted by comparing them to regional reservoir yields. The safe yield of New England large water supply reservoirs is typically about 600,000 gallons per day per square mile of watershed for the 1960's droughts (NEWWA 1974; Soule 1969). This typical safe yield is less than the total annual runoff because some flow spills over in wet periods and is not retained. The 0.5 cfsm ABF release rate is 53 percent of the typical safe yield, while the 0.2 cfsm release rate used in Connecticut's Minimum Stream Flow Standards represent 21 percent of the safe yield.

Much of the difficulty lies in the inability to forecast future precipitation and runoff conditions. During wet years, many reservoirs could be drawn down to release water for maintaining summer instream flows, then refill in the winter and spring. However, reservoir operators are naturally reluctant to release water in dry summers because they do not know if it will be followed by a dry or wet winter. By the time instream flow releases are reduced in water supply emergencies, much of the excess water is already gone.

Appendix E – Estimating Natural Daily Streamflow at Ungaged Sites

[Note: This is not an endorsement by the Subcommittee of these methods but a summary of the presentation by Dr. Fennessey]

On May 30, 2002 Dr. Neil M. Fennessey (2002b) made a presentation to the Subcommittee describing how to generate a long record of estimated daily flows at ungaged location, such as a site of an existing or proposed diversion.

Currently, there are two ways available to generate a long record of estimated, natural (unregulated) daily flow data at ungauged locations in Connecticut. Estimates of daily flows at ungauged locations are necessary to test the efficacy of proposed rules and regulations on the needs of riparian ecology and the potential impacts or changes that would be imposed on the regulated community. The proposed instream ecological goal flow monthly statistics, suchs as Apse (2000), can be directly estimated from the data generated. One techniques lies in the realm of rainfall-runoff modeling and the other is a special transformation of historic streamgauge observations referred to as the QPPQ transform.

Rainfall-Runoff Models

The Stanford Watershed Model (SWM) described by Viessman and Lewis (1996), developed by Crawford and Linlsey (1966), is recognized as the forerunner of today's generation of physically based research and operational rainfall runoff models. A lumped, physically based, deterministic approach to generating estimates of daily streamflow, represents the passage of precipitation upon the watershed's water body surface, soil and vegetative surface then through the upper and lower soil layers and ultimate discharge into a stream channel. It models direct runoff, soil water interflow and the slower responding baseflow. Evapotranspiration is possible from both upper and lower soil layers. Major parameters include the necessary specification of maximum storage amounts of tension and free water in each zone, the rates of passage between zones based upon storage volumes. Requiring over 25 model parameters, including daily precipitation and evapotranspiration, SWM requires 3-6 years of daily streamflow data (i.e. a streamgauge) collected at the target location to calibrate the model, and then additional data to validate the model. The model output is runoff with a daily time step.

A variation of the SWM is the National Weather Service River Forecast System model. Used for generating flood forecasts, the NWSRF model output timestep is 6 hours. Kirshen and Fennessey (1995) used this version of SWM in conjunction with the 13 parameter National Weather Service *Snow Accumulation and Ablation Model* to generate daily flows in the Connecticut River, the Nashua River and Ware River in Massachusetts. As described by Fennessey and Kirshen (1994), the NWSRF model requires estimates of daily evapotranspiration and the MWRA operations model requires estimates of reservoir evaporation, the Penman-Monteith and Penman equations were used. The Penman and Penman-Monteith models require NOAA First Order weather observatory data that in Connecticut, is available only in Hartford and Bridgeport, as described by Fennessey and Vogel (1996).

Hydrocomp, Inc developed a commercial version of the Stanford Watershed Model. It was named the Hydrocomp Simulation Package (HSP) and incorporated water quality modeling routines. In 1980, the US EPA funded the development of HSPF (Hydrocomp Simulation Package FORTRAN), the public domain version of HSP, changing the computer language from ALGOL to FORTRAN-77 and incorporating yet more water quality modeling routines. With regard to generating 'natural" runoff (i.e. pre-anthropogenic influence), several model parameters can be varied in HSPF. These include: (1) the impervious fraction of the watershed surface (2) Manning roughness coefficient for overland flow (SWM incorporates Kinematic Wave routing) (3) Manning roughness coefficient for impervious area; (4) surface storage capacity index; (5) fraction of watershed area covered by phreatophytes and (6) volume of water in swamp (wetlands) storage. Parameters that drive the routines in HSPF must be estimated for all hydrological processes, making model calibration and validation a difficult exercise. HSPF requires over 35 different parameters. The Massachusetts Office of the USGS employed HSPF to explore alternative management practices in the Ipswich River basins.

The QPPQ Transform

Fennessey (1994) developed the QPPQ transform as an improvement over what is referred to as the watershed area ratio transform. In the watershed area ratio transform, the runoff from an ungauged watershed is assumed to be a linearly scaled copy of the gauged watershed's response, but otherwise identical in every other characteristic. The scaling factor is the fraction the ungauged watershed's area divided by the area of the gauged watershed. It is widely recognized that there are other factors responsible for a watershed's unique runoff signature, these differences being the motivation for the development of the Stanford Watershed Model.

Recognizing the difficulty in calibrating and validating rainfall-runoff models, impossible in the absence of the required streamgauge, Fennessey developed the QPPQ transform, a procedure that generates daily streamflow at an ungauged site, which driven by an historic record of daily streamflow observed at an unregulated stream gauge. The QPPQ transform, proven to be an improvement over the watershed area ratio transform, is applicable to New York, Pennsylvania, New Jersey and all of the New England states, including Connecticut. It has been used in the past for several studies in Massachusetts and is currently being used to assess the firm yield of several water supply reservoir systems there as well. The QPPQ transform has also been used for several studies in Connecticut, including the on-going Quinebaug River MesoHABSIM study collaboration between Cornell University and HYSR, Inc.

Because the QPPQ transform generates daily flows at some chosen location on a stream or river, it is then a simple matter to generate site-specific streamflow statistics. For example, the QPPQ transform can be used to develop a site-specific estimate of the US F&WS ABF median of the monthly mean daily streamflow or alternatively, the monthly median of daily flows (daily Q50, the C. Aspe (2000) October-June statistic), the monthly mean daily flow, or the weekly averaged or median daily flow or even the 7Q10 low-flow statistic, etc. The QPPQ transform, more parameter parsimonious than the Stanford Watershed Model, requires site specific estimates of the contributing watershed area; average watershed elevation; main stream channel slope, watershed relief; the mean annual precipitation and the mean annual snowfall and the USDA

NRCS maximum soil moisture retention, P. Parameter P, which is used to estimate the NRCS runoff curve number, CN, depends on both the soil's hydrologic characteristics what that soil is covered with, such as forest, pasture, wetlands, ½ acre developed building lots, etc.